

312 represents the concentration of electrons. The intermediate band electrons in the thickness range 0.18 to 0.32 m in layer 106 (FIG. 1) are electrically isolated from the back contact by the blocking layer 104. Only the electrons that are excited from the intermediate band 212 (FIG. 2) to the upper band 214 can be transferred to the substrate and collected by the back contact. Therefore, the carrier concentration profile graph of FIG. 3 shows that the blocking layers function properly and work effectively as blockers of electrons and holes, which electrically isolates the IBand improving the current, voltage and the overall power conversion efficiency of IBSC 100.

Referring now to FIG. 4, a block diagram representation of a test device structure of an IBSC 300 having metal contacts 414 and 416 and being exposed to sunlight 401 is shown generally in accordance with one or more embodiments of the present disclosure. IBSC 400 includes a 90 nm n $\text{Al}_{0.44}\text{Ga}_{0.56}\text{As}$ blocking layer 404 is formed on an n⁺ GaAs substrate layer 402. A 400 nm n-type GaNAs layer 406 is formed on the n AlGaAs blocking layer 404, and a 100 nm p⁺-type GaNAs layer 408 is formed on the n-type GaNAs layer 406. A 50 nm p⁺⁺ $\text{Al}_{0.45}\text{Ga}_{0.55}\text{As}$ blocking layer 410 is formed on the GaNAs layer 408 and finally a 20 nm p+-GaAs protective contact layer 412 is formed on the AlGaAs blocking layer 410. An InZn bias contact 414 is formed on the protective layer 412 with an InSn ground contact 416 being formed on a portion of the substrate layer 302. Bias contact 414 serves as a contact for a voltage or voltage source, and ground contact 416 serves as a contact for a grounding voltage. Bias contact 414 may comprise InZn (Indium Zinc) and ground contact 416 may comprise InSn (Indium Tin) in this particular embodiments, while it is understood that other ohmic contact metallizations to p-type and n-type GaAs providing similar desired characteristics could be utilized for any of the respective layers and components of IBSC 400.

Referring now to FIG. 5, a graphical illustration of the current-voltage I-V characteristics measurements in the dark and under 1x and 10x sun illumination for the IBSC 400 of FIG. 4 is shown in accordance with one or more embodiments of the present disclosure. I-V characteristics plots of FIG. 5 show a bias voltage (in V) for its x-axis and a current density, measured in mA/cm², as its y-axis. Plot 512 shows the I-V characteristics of IBSC 400 of FIG. 4 upon exposure to 1x sun AM1.5, while plot 514 shows the I-V characteristics when IBSC 400 is shielded from the sun (i.e., dark). Similarly, plot 516 shows the I-V characteristics of IBSC 400 of FIG. 4 upon exposure to 10x sun AM1.5, while plot 518 shows the I-V characteristics when IBSC 400 is shielded from the sun (i.e., dark). As can be clearly seen in FIG. 5, when IBSC 400 is exposed to sun for given voltage biases, the current increases drastically, thereby illustrating that the IBSC 400 functions properly as it turns photons into electrons and current. The V_{OC} , the voltage at zero current under illumination for the 1x and 10x sun condition are 0.75, and 0.8 eV, respectively. These values of V_{OC} are much higher than those for unblocked structures reported in the literature (0.3-0.4 eV).

Referring now to FIG. 6, a graphical illustration of the External Quantum Efficiency (EQE) reading of the IBSC 400 of FIG. 4 is shown in accordance with one or more embodiments of the present disclosure. EQE graph of FIG. 6 illustrates the energy of the exciting monochromatic light in eV along its x-axis and an photovoltaic response EQE in percentage (%) along its y-axis. EQE plot 612 shows the effective blocking of the intermediate band by usage of the blocking layers discussed above. High EQE values are achieved only

when the exciting light reaches the energy separation between the valence band and the higher conduction band of the GaNAs layer ~2 eV.

In one or more embodiments, the nitrogen concentration x in at least one or both of the GaN_xAs absorber layers of the P-N junction of an IBSC 800 can be compositionally graded in order to improve the performance of the IBSC 700 as illustrated in FIG. 8A. Either or both of the GaNAs layers 808 and 810 (which correspond to GaNAs absorber layers 106 and 108) can be graded from a higher nitrogen concentration x of ~0.02 in one portion of the GaN_xAs layer 808 or 810 to a lower nitrogen concentration of x~0.005 in another portion 806 of the same GaN_xAs layer 808 or 810. For example, within the GaNAs layer 808, the N concentration decreases from x=0.018 near the interface between GaN_{0.018}As layers 808 and 810 to x=0.005 near the interface between GaN_{0.005}As layer 808 and blocking layer 804. In one or more embodiments, the portions of the GaNAs layers 808 and 810 closest to their junction will have the highest concentration of nitrogen. By compositionally grading at least one of the GaNAs layers 808 and 810, an additional potential is created that drives electrons toward the n-GaAs substrate 802, thereby increasing cell current. Further, the compositional grading of GaNAs layers 808 and 810 will provide a larger gap at their surfaces, thereby likely forming a better hole-conducting contact. These advantages associated with the compositional grading will further increase the solar power conversion efficiency of this type of solar cell.

Referring now to FIG. 8B, a graphical illustration of the calculated band diagram for the IBSC 800 of FIG. 8A is shown in accordance with one or more embodiments of the present disclosure. The calculated band diagram of FIG. 8B includes plots for the conduction band (E_C) 822, the intermediate band (IBand) 824, and energy of the valence band (E_V) 826. It can be seen from these band diagrams that the intermediate band 824 is effectively isolated from the conduction band (E_C) of the substrate and the top contact layer. When comparing the band diagrams of the graded structure, shown in FIG. 8B, with those of the non-graded structure, shown in FIG. 2, it can be seen from the band diagrams of FIG. 8 that the conduction band (E_C) 822 and the valence band (E_V) 826 of the graded structure have greater slopes in the absorber layer than the corresponding conduction band (E_C) 212 and the valence band (E_V) 214 of the non-graded structure, thereby showing the additional potential created in the graded structure that drives electrons away from the p-n junction.

In accordance with one or more embodiments, an intermediate band solar cell (IBSC) is provided that utilizes dilute Group III-V nitride intermediate band materials and contact blocking layers in order to improve solar cell performance. Specifically, overall advantages of the present disclosure include being able to increase the open circuit voltage values, increase the photocurrent generated by increased light absorption through the isolated IBand, and hence ultimately being able to improve the overall power conversion efficiency and performance of a IBSC by effectively isolating the IBand using blocking layers. Furthermore, because an IBSC is utilized, only a single P-N junction is required, which, along with contact blocking layers, considerably simplifies cell design and thus significantly lowers production costs in comparison with multijunction designs.

While an intermediate band solar cell using grading compositions and contact blocking layers has been described in terms of what are presently considered to be the most practical and preferred embodiments, it is to be understood that the present disclosure need not be limited to the above embodiments. It should also be understood that a variety of changes